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COMBUSTION HOT SECTION TECHNOLOGY

David B. Ercegovic

Propulsion Laboratory
AVARDCOM Research and Technology Laboratories
Lewis Research Center
Cleveland, Ohio

The overall objective of the Turbine Engine Hot Section Technology Combustion Project is to develop and verify improved and more accurate analysis methods for increasing the ability to design with confidence the combustion system for advanced aircraft turbine engines. The analysis methods developed will be generically applicable to combustion systems and not restricted to one specific engine or manufacturer.

This project's approach was to first assess and evaluate existing combustor aerothermal analysis models by means of a contracted effort initiated during FY '82. This evaluation effort has assessed and quantified known models' strengths and deficiencies. The results of this assessment will be summarized later in this report by the three contractors Garrett, General Electric and Pratt and Whitney Aircraft who conducted this independent evaluation. A balanced contract and in-house program will then be conducted to support, focus, and accelerate the development of new methods to more accurately predict and model the physical phenomena occurring within the combustor. This program will include both analytical and experimental research efforts in the areas of aerothermal modeling and liner cyclic life.

During FY '84 the Aerothermal Modeling Program - Phase II will be initiated, which is expected to have contracted model development efforts in the areas of improved numerical methods for turbulent viscous flows, flow interactions, and fuel spray flow-field interactions. A Phase III effort is planned to address remaining model deficiencies. The primary in-house effort in this area will be the determination of high pressure flame radiation characteristics in a full annular combustor. This experiment will be conducted in the NASA LeRC High Pressure Facility with the results compiled into a comprehensive flame radiation and liner heat flux model.

In the area of liner cyclic life, HOST is engaged in a co-operative effort with Pra-t and Whitney Aircraft to develop a test apparatus to economically determine combustor thermal strains and cyclic life. This test apparatus will be run in-house at NASA LeRC and will be the test vehicle for many of the advanced high temperature instruments developed under HOST sponsorship. The fundamental data generated in this project will be used to assess and further develop current analytical liner life programs.

COMBUSTION

PROGRAM ELEMENT	FISCAL YEAR 81	82	83	84	85	86	87	EXPECTED RESULT
AEROTHERMAL MODELING ASSESSMENT PHASE I:								
GARRETT								IDENTIFY MODEL AND BENCHMARK DATA DEFICIENCIES
GENERAL ELECTRIC								
PRATT & WHITNEY								
AEROTHERMAL MODEL DEVELOPMENT PHASE II:								—
MASS & MOMENTUM TRANSFER (P&W)								NEW PHYSICAL MODEL AND COMPUTING METHODS
NUMERICAL METHODS (TBD)								
FLOW INTERACTIONS (TBD)								
FUEL SPRAY-FLOWFIELD INTERACTIONS (TBD)								
AEROTHERMAL MODEL DEVELOPMENT PHASE III: (TO BE DETERMINED)								—
MULTIPLE JET DILUTION MIXING: GARRETT								EXIT TEMPERATURE PROFILE PREDICTION TECHNOLOGY
FLAME RADIATION/HEAT FLUX	(IH)							HIGH PRESSURE FLAME RADIATION AND HEAT FLUX
DILUTION JET ANALYSIS	(IH)							JET MIXING MODEL
LINER CYCLIC RIG CO-OPERATIVE (P&W)	(IH)							CYCLIC TEST FACILITY

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AEROTHERMAL MODELING PROGRAM - PHASE I

R. Srinivasan, R. Reynolds, K. Johnson, and H. Mongia
Garrett Turbine Engine Company

The main objective of the NASA-sponsored Aerothermal Modeling Program, Phase I, was to assess current aerothermal submodels used in the Garrett Turbine Engine Company (GTEC) analytical combustor models.

A number of "benchmark" quality test cases were selected after an extensive literature survey (ref. 1). The selected test cases, including both nonreacting and reacting flows, were broadly divided into the following categories:

- Simple flows
- Complex nonswirling flows
- Swirling flows
- Dilution jet mixing in confined crossflows.

These test cases were used to assess the following submodels separately and jointly for various combustion processes:

- $k-\epsilon$ model of turbulence and algebraic stress model, with and without various corrections, including low Reynolds number and Richardson number corrections
- Scalar transport models
- Multistep kinetic schemes
- Turbulence/chemistry interaction
- Spray combustion.

Based upon the Phase I work, the following assessments of the submodels were made:

- The $k-\epsilon$ model and its modifications give good correlations for
  - Simple flows
  - Far-field regimes of nonswirling/swirling flows involving regions of recirculation
  - Non-recirculating swirling flows
  - Outer regions of strong swirling flows.

- These models give reasonable correlations for
  - Nonswirling recirculating flows excluding the vicinity of any attachment point
  - Confined disk flow with a central jet
  - Shear layer of strong swirling flows
  - Confined swirler with hub and shroud expansions.

The $k-\epsilon$ model and its modifications predict only the trends in recirculation zones of swirling flows and confined swirler flows without outer expansion.

The Reynolds stresses predicted by the algebraic stress model (ASM) correlate well for simple flows. The ASM correctly predicts the normal stresses in nonswirling recirculating flows. The ASM predictions give reasonable correlations for:

- Shear stresses in nonswirling recirculating flows
- Normal stresses in swirling flows.

For predicting the scalar transport, the $k-\epsilon$ model with constant Prandtl number gives good correlation where the gradient diffusion approximation is valid. The algebraic scalar transport model is a promising approach and more validation efforts are needed.

On the turbulence/chemistry interaction models, the following general conclusions were made:

- Both two-step and four-step kinetic schemes show promise
- A modified eddy breakup model can easily be extended to multistep kinetic schemes
- Bilger's two-reaction-zone model gives good results for jet flames, but requires more work.

When dilution jet mixing was considered, the three-dimensional analytical model had the following characteristics:

- Slightly underpredicted jet penetration
- Centerline temperatures predicted well
- Transverse mixing predictions slower than data
- Effect of S/D, H/D, J on mixing predicted correctly (where D = geometric orifice diameter, H = local duct height at the survey plane, J = jet versus mainstream momentum ratio, S = orifice spacing)

- o Good correlation for jet injection from
  - One wall
  - Both walls - inline orifices
  - Both walls - staggered orifices

The following general conclusions were derived from the Phase I work (ref. 2):

- o An accurate numerical scheme should be developed to minimize numerical diffusion in the computations of recirculating flows
- o Benchmark quality data should be generated under well defined environments for validating the various submodels used in gas turbine combustion analysis
- o Although current aerothermal models make reasonable predictions, intensive model development and validation efforts should continue for the following submodels:
  - Algebraic stress model
  - Algebraic scalar transport model
  - Two-step and four-step schemes
  - Probability density function approach for a two-step scheme
  - Double-reaction-zone model.

REFERENCES

1. Srivatsa, S.K.; Srinivasan, R.; and Mongia, H.C.: Aerothermal Modeling Program, Phase I - Subtask 1.2 Report, Data Base Generation. Garrett Turbine Engine Company Report 21-4484, September 1982.

2. Srinivasan, R.; Reynolds, R.; Ball, I.; Berry, R.; Johnson, K.; and Mongia, H.: Aerothermal Modeling Program, Phase I, Final Report. Garrett Turbine Engine Company Report 21-4742, August 1983.